Nuclear data Exercises

1. What is the total energy released (Q-value) in the spontaneous transformation of Po-210 to Pb-206 by alpha emission?
   5.40745 MeV

2. What is the a) average, and b) maximum alpha particle energy for the spontaneous transformation of Pu-239?
   a) α mean energy = 5.238 MeV
   b) α max energy = 5.2445 MeV

3. What is the maximum kinetic energy of the betas released in the spontaneous transformation of Sr-89 to Y-89?
   1.4951 MeV

4. What is the average beta kinetic energy? Note that the average kinetic energy is approximately 1/3 of the maximum value.
   584 keV
5. 4. The decay of Fe-55 by electron capture to Mn-55 can be written Fe-55 → Mn-55* + ν in which an inner shell electron in Fe-55 is captured by the nucleus and combines with a proton (i.e. e + p → n + ν) in the nucleus to form a neutron and a neutrino ν. The process of electron capture leaves a vacancy in an electron shell that is then filled immediately by electrons form higher levels cascading down. The process is characterised by the emission of xrays and associated Auger electrons.
   a). What is the total decay energy (Q-value) for this reaction?
   0.23138 MeV
   b) What is the energy of the mono-energetic neutrino created in this reaction?
   231.4 - 4.0 - 1.7 = 225.7 keV
   c). What percentage of the total decay energy is carried away by the neutrino?
   225.7 / 231.4 * 100 = 97.5%
   d). What is the isotopic (heat) power of Fe-55?
   79.8 mW/g
   e). What is the total power (per gram) emitted?
   79.8e-3 / 2.5 * 97.5 = 3.16 W/g
6. Nuclear reactor power is driven by the nuclear fission of U-235 with thermal neutrons (E= 0.025 keV = 2.2km/s).
   a. How much is fission predominant compared to neutron capture – (n,γ) reaction- and scattering?
      583.2/(15.11+98.95) = 5.11 times

b. Find the two main fission products from the thermal fission of U-235 with half-lives within 25-35 years.
55Cs-137 and 38Sr-90

c. Assuming an average 3 neutrons emission by fission determine for the two fission products found in 6.b. the other fission products produced during the binary fission.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow \left(^{236}_{92}U\right)^{*} \rightarrow {}^{A}_{z}X + {}^{236-A-3}_{92-z}Y + 3\cdot{}^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow \left(^{236}_{92}U\right)^{*} \rightarrow {}^{137}_{55}Cs + {}^{96}_{37}Rb + 3\cdot{}^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow \left(^{236}_{92}U\right)^{*} \rightarrow {}^{137}_{55}Cs + {}^{96m}_{37}Rb + 3\cdot{}^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow \left(^{236}_{92}U\right)^{*} \rightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3\cdot{}^{1}_{0}n$$

Rb96, Rb96m, Xe143

d. What's the amount of the 4 fission products produced per 1 tone of U-235?

Number of U-235 nuclides: $N_U = N_A / A_U * M_U$
Amount produced: $M_X = N_U * Y_{CumulX} / N_A * A_X$
$M_X = Y_{CumulX} * A_X / A_U * M_U$

6.22e-2 * 136.907 / 235.044 = 36.2 kg Cs-137
5.73e-2 * 89.908 / 235.044 = 21.9 kg Sr-90
1.76e-3 * 95.934 / 235.044 = 0.72 kg Rb-96
6.75e-4 * 95.934 / 235.044 = 0.28 kg Rb-96m
7.89e-4 * 142.935 / 235.044 = 0.48 kg Xe-143

e. What's the decays heat produced by the two fission products found in 6.b.?

Cs-137 decays heat: 9.67 W/g * 36.2 kg = 350 kW
Sr-90 decays heat: 0.142 W/g * 21.9 kg = 3.11 kW

f. What amounts of U-235 shall be fissioned in order to produce the annual limits of toxicity (inhalation and ingestion) for the two fission products found in 6.b.?

ALI_{inh} of Cs-137 = 5.13e5 Bq = 1.595e-7g → 1.595e-7g/36.2 kg/t = 4.42 µg U-235
ALI_{ing} of Cs-137 = 1.54e6 Bq = 4.79e-7g → 4.79e-7g/36.2 kg/t = 13.2 µg U-235
ALI_{inh} of Sr-90 = 1.25e5 Bq = 2.45e-8g → 2.45e-8g/21.9 kg/t = 1.12 µg U-235
ALI_{ing} of Sr-90 = 7.14e5 Bq = 1.40e-7g → 1.40e-7g/21.9 kg/t = 6.40 µg U-235

7. The fast neutron activation was found to be an efficient, quick and accurate method of characterizing the precious metal objects routinely in bulk, with a large sample throughput. In this exercise the researcher is interested to analyze gold jewelry using neutron activation.

a. Describe the reaction (parent/daughters of the reaction)

$$^{197}_{79}Au + ^{1}_{0}n \rightarrow ^{198}_{79}Au + \gamma$$

b. Looking at the cross-section, which neutron spectrum is more favorable for the activation?

Epi thermal neutron: 1562 barn (resonance integral)

c. The researcher is interested in prompt gamma emission. Which lines will he measure?

214.971 keV, 247.573 keV, 262.404 keV (…734 lines)

d. If he were doing delayed gamma spectroscopy, which lines would he measure?

411.802 keV, 675.884 keV, 1087.68 keV (from Au-198)

e. The researcher is actually irradiating a 2 g gold sample (18 carats i.e. 75% gold content) with a 14 MeV neutron flux of 4.10^{7} $n.cm^{-2}.s^{-1}$ during 1 min. How much activated gold (atoms and grams) did he produced at the end of the irradiation? What does that activated gold becomes after 27 days?

$N_{Au-198} = \Phi * t * \sigma * N_A * M_{Au-197} / A_{Au-197}$

$N_{Au-198} = 4e7 * 60 * 1e-3 * 1e-24 * 6.023e23 * 1.5 / 196.967$

$N_{Au-198} = 11000$ Au-198 atoms

$M_{Au-198} = N_{Au-198} * A_{Au-198} / N_A$

$M_{Au-198} = \Phi * t * \sigma * M_{Au-197} * A_{Au-198} / A_{Au-197}$

$M_{Au-198} = 4e7 * 60 * 1e-3 * 1e-24 * 1.5 * 197.968 / 196.967$

$= 3.62e-18$ g Au-198

After 27 days (10 half lives) Au-198 is fully decayed into stable Hg198